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Compression of 1-mm-thick M9763 cellular silicone foam under lateral confinement

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SUMMARY

M9763 cellular silicone foam disks (1 mm thick, 28.68 mm diameter, 63% nominal porosity) were compressed under lateral confinement using the Instron Electropuls E10000 load frame. Five (5) load-unload cycles up to 65% compressive strain were performed at a test speed of 1.26 mm/min. Stress vs. strain curves were obtained. Additional specimens were compressed without lateral confinement for comparison. The stress vs. strain curve of the confined specimen essentially overlapped that of the unconfined specimen until ~60% strain when it began to increase more rapidly, indicating lock-up (bulk compression) and the onset of lateral expansion of the unconfined specimen. The slope of the stress vs. strain curve was equal to the Young's modulus of the solid M9787 material comprising the foam at ~50% strain, which is below the expected 63% lock-up strain. The reason for the discrepancy between the two estimates of lock-up strain is not clear.

MATERIALS AND METHODS

Circular disk specimens were cut from a 1-mm-thick sheet of M9763 cellular silicone foam (Lot # PRJ044734-001, BBN-1023-K07) using a press with a 1.129 inch (28.68 mm) diameter die (specimen area = 1 sq in). The nominal porosity of the foam was 63%. The actual porosity was calculated to be ~64% based on the densities of the foam (0.42 g/cm^3) and solid M9787 (1.15 g/cm^3) comprising the foam (measured by weighing a known volume of each material), which is in good agreement with the nominal value.

Testing was conducted in B131HB R1331. The Instron Electropuls E10000 load frame with a 10 kN load cell was equipped with a 1.129 in (28.68 mm) diameter fixed upper platen and a 4 inch diameter spherical seat lower platen. The platens were parallel to within 0.005 mm. A lateral confinement fixture consisting of a 1.130 in (28.70 mm) diameter well to provide a frictionless sliding fit with the upper platen (Fig. 1) was placed on the lower platen. The specimen was seated in the well of the confinement fixture such that it was flush with the bottom and side wall of the well to prevent lateral expansion during compression (Fig. 2a).

Five (5) load-unload cycles up to 65% compressive strain were performed at a test speed of 1.26 mm/min at room temperature. Load and displacement were recorded at 20 Hz. The displacement was corrected for instrument compliance after testing, and compressive engineering stress (σ) and strain (ε) were calculated using the formulas

$$\sigma = \frac{P}{A} \text{ and } \varepsilon = \frac{d_0 - d}{d_0}$$

where P is the applied load, A is the original specimen area (equal to the upper platen area), d_0 is the original specimen thickness, and d is the specimen thickness under load. The original specimen thickness was given by the displacement at a load of 2 kPa during the first load. Two specimens were tested. Two additional specimens were compressed without lateral confinement for comparison using the 1.129 in diameter upper platen and 4 in diameter lower platen (Fig. 2b).

Lock-up (bulk compression) was expected to occur at a compressive strain of 63% based on the nominal foam porosity. The onset of lock-up was estimated using two different methods. The first estimate was given by the strain at which the stress vs. strain curve of the confined specimen began to deviate from that of the unconfined specimen; the two curves are expected to coincide until the unconfined specimen begins to laterally expand, which is expected to occur at lock-up. The second estimate was given by the strain at which the slope of the stress vs. strain curve is equal to the Young's modulus of the of solid M9787 material comprising the foam (1.7 MPa measured by Small [1] or 1.9 MPa according to DeTeresa [2]).

RESULTS AND DISCUSSION

Displacement and compressive load are each plotted as a function of time for confined and unconfined specimens in Fig. 3. The peak stress of the confined specimen did not decrease with cycle, suggesting that the foam structure was not damaged by the test. Though it did not affect the results of this study, it is worth noting that the test speed was not maintained as the crosshead changed direction at high loads (~7-9 kN), as revealed by the curved shape of the displacement vs. time curve for the confined and unconfined specimens during each load-unload transition.

Compressive stress vs. strain curves for confined and unconfined specimens are shown in Fig. 4. The stress vs. strain curve of the confined specimen essentially overlapped that of the unconfined specimen until ~60% strain when it began to increase more rapidly, indicating lock-up (bulk compression) and the onset of lateral expansion of the unconfined specimen. This estimate of lock-up strain is in good agreement with the expected value of 63%. Note that selection of the onset of deviation of the two curves is subjective, as slight deviation was apparent at lower strain by zooming in on the curves. The slope of the stress vs. strain curve (for both the confined and unconfined specimens) was equal to the Young's modulus of the solid M9787 material comprising the foam at ~50% strain. The reason for the discrepancy between the two estimates of lock-up strain is not clear. On a related note, the slope of the stress vs. strain curve (unconfined compression) for a nominal 50% porous structure additively manufactured from Dow Corning SE 1700 silicone elastomer by direct-ink-writing [3] was equal to the Young's modulus of solid SE 1700 (3.3 MPa measured by Small [4]) at ~48% strain, which is quite close to the expected lock-up strain of 50%.

Photographs of a foam specimen during an unconfined test are shown in Fig. 5. Lateral expansion of the foam was evident during compression.

The agreement between the stress vs. strain curves of the confined and unconfined specimens up to ~60% strain suggests that the confinement fixture was essentially frictionless and did not trap air in the headspace between the specimen and the upper platen.

CONCLUSIONS

Stress vs. strain of 1-mm-thick M9763 cellular silicone foam was measured as the foam was compressed under lateral confinement. Compression without confinement was also performed for comparison. Lock-up (bulk compression) occurred in both the confined and unconfined tests. The lock-up strain was estimated to be ~60% based on the strain at which the confined and unconfined stress vs. strain curves began to deviate from each other and ~50% based on equivalence of the slope of the curve and the Young's modulus of solid M9787 comprising the foam. Similar results were previously obtained for 2-mm-thick M9763 foam [5].

ACKNOWLEDGMENT

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REFERENCES

1. Experiment conducted on 01/29/2014.
2. S. DeTeresa. Bulk modulus of solid M9787 silicone rubber at room temperature. MMED Memo 98-154 ETR#9809794 (October 27, 1998).
3. Specimen ID# 2013-03-15-TM-03 Part 4D.
4. Experiment conducted on 02/26/2013.
5. Experiment conducted on 04/21/2014.

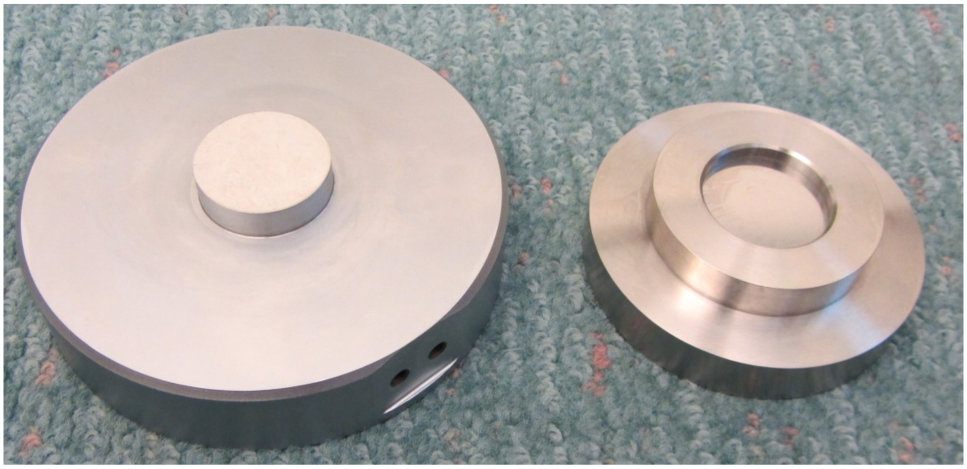


Fig. 1. (Left) 1.129 in diameter upper platen and (right) lateral confinement fixture with a 1.130 in diameter well (sliding fit with the upper platen) to contain the foam specimen. The depth of the well is 0.15 in (3.8 mm). The fixture was placed on the lower 4 in diameter platen for testing.

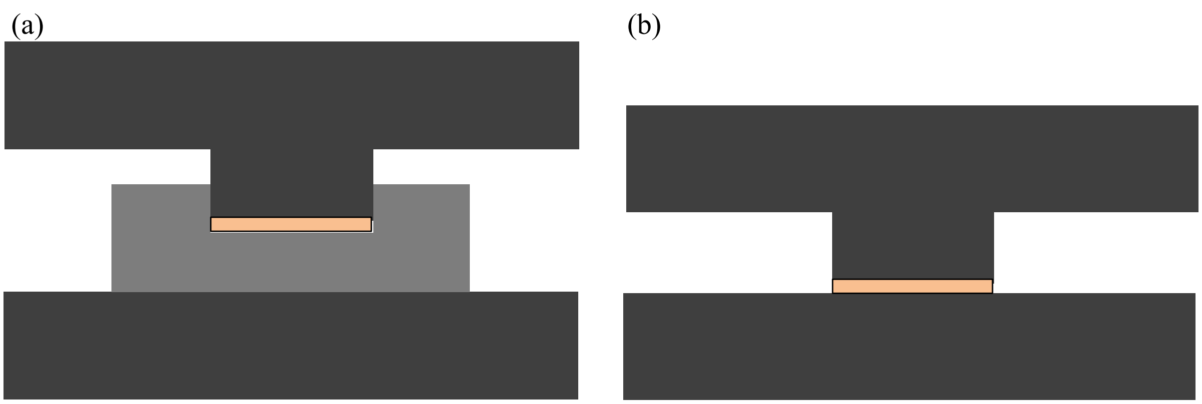
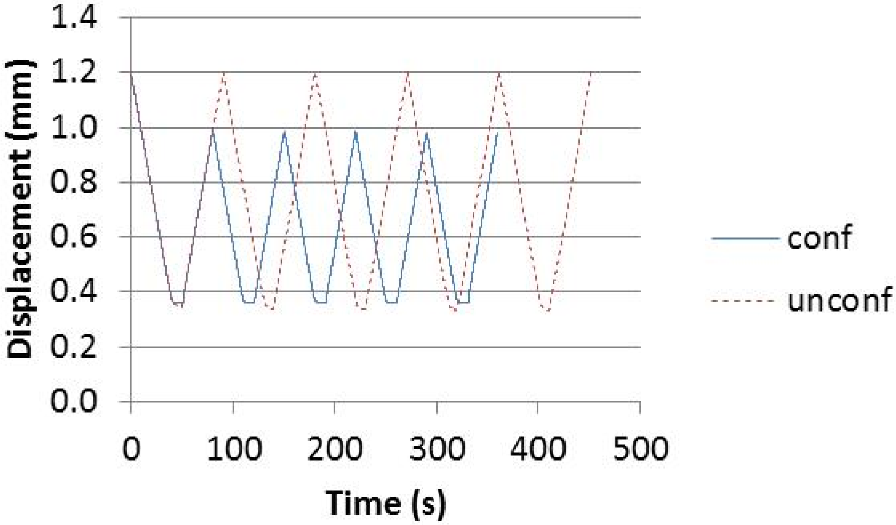


Fig. 2. Schematic diagrams of (a) laterally confined and (b) unconfined compression of the M9763 foam.

(a)



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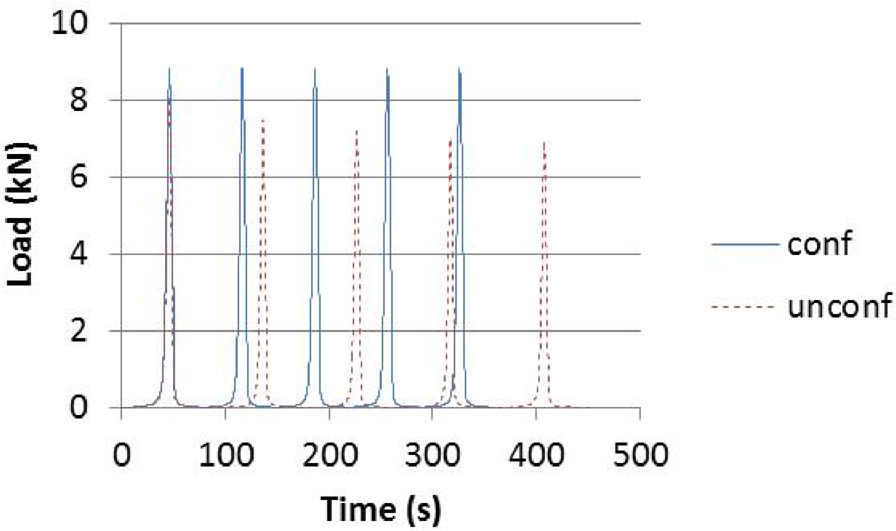
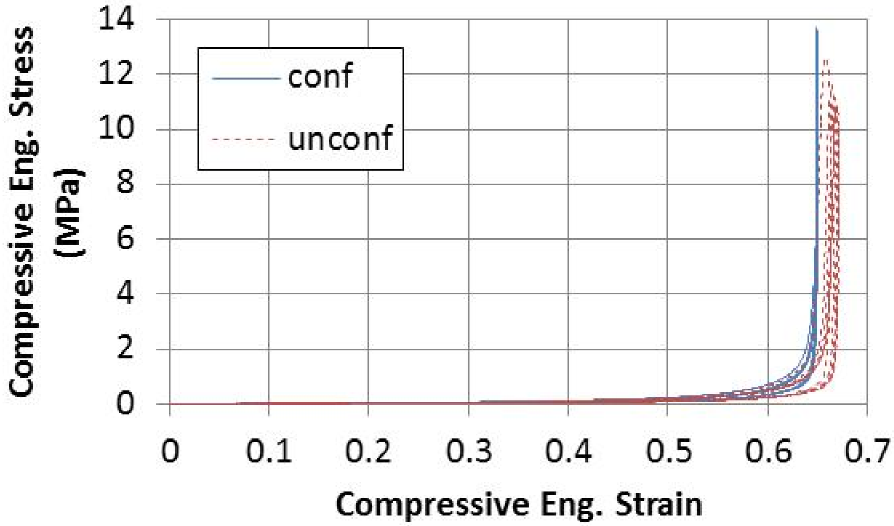


Fig. 3. (a) Displacement (corrected for instrument compliance) and (b) compressive load vs. time for laterally confined and unconfined M9763 foam specimens. Displacement was corrected for instrument compliance. For the confined test, the upper platen moved up during unloading until the measured load was zero. For the unconfined test, the upper platen moved up beyond the top surface of the specimen during unloading to allow the specimen to resume its original diameter before starting the next loading cycle. Though it did not affect the results of this study, it is worth noting that the test speed was not maintained as the crosshead changed direction at high loads (~7-9 kN), as revealed by the curved shape of the displacement vs. time curve for the confined and unconfined specimens during each load-unload transition.

(a)



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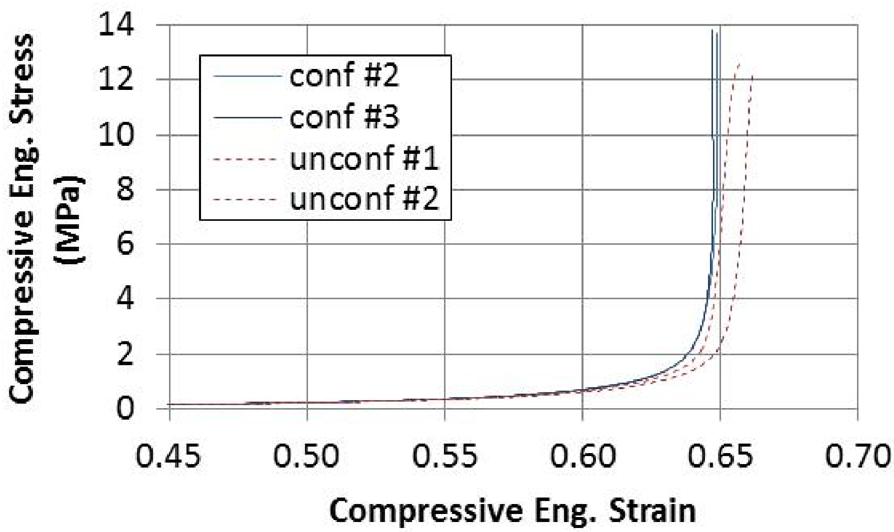

Fig. 4. Compressive stress vs. strain plots of laterally confined and unconfined M9763 foam specimens showing (a) all five load-unload cycles and (b) the first load above 45% strain. Replicate specimens are included in (b). The confined and unconfined curves in (b) are nearly identical until ~60% strain.

(a) (b)

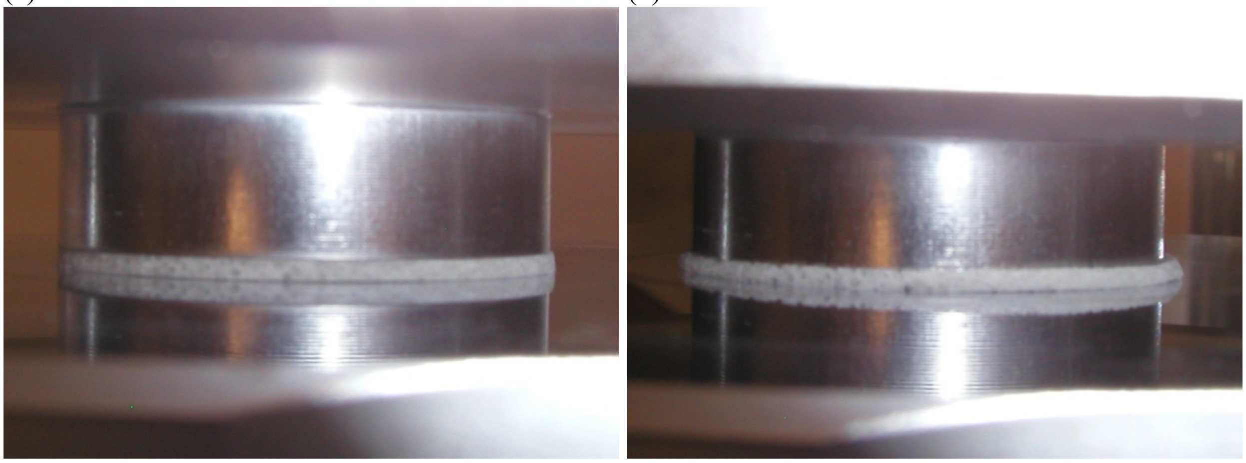

Fig. 5. Photographs of a M9763 foam specimen at (a) 0% and (b) 65% compressive strain showing lateral expansion of the foam during an unconfined test. The upper platen is buried in the foam in (b); the platen face is hidden by the uncompressed foam that has been extruded out. A reflection of the foam and upper platen is seen in the lower platen.